Diffractive χ Production at the Tevatron and the LHC

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Outline

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- Exclusive χ_{C_0} Production at the LHC
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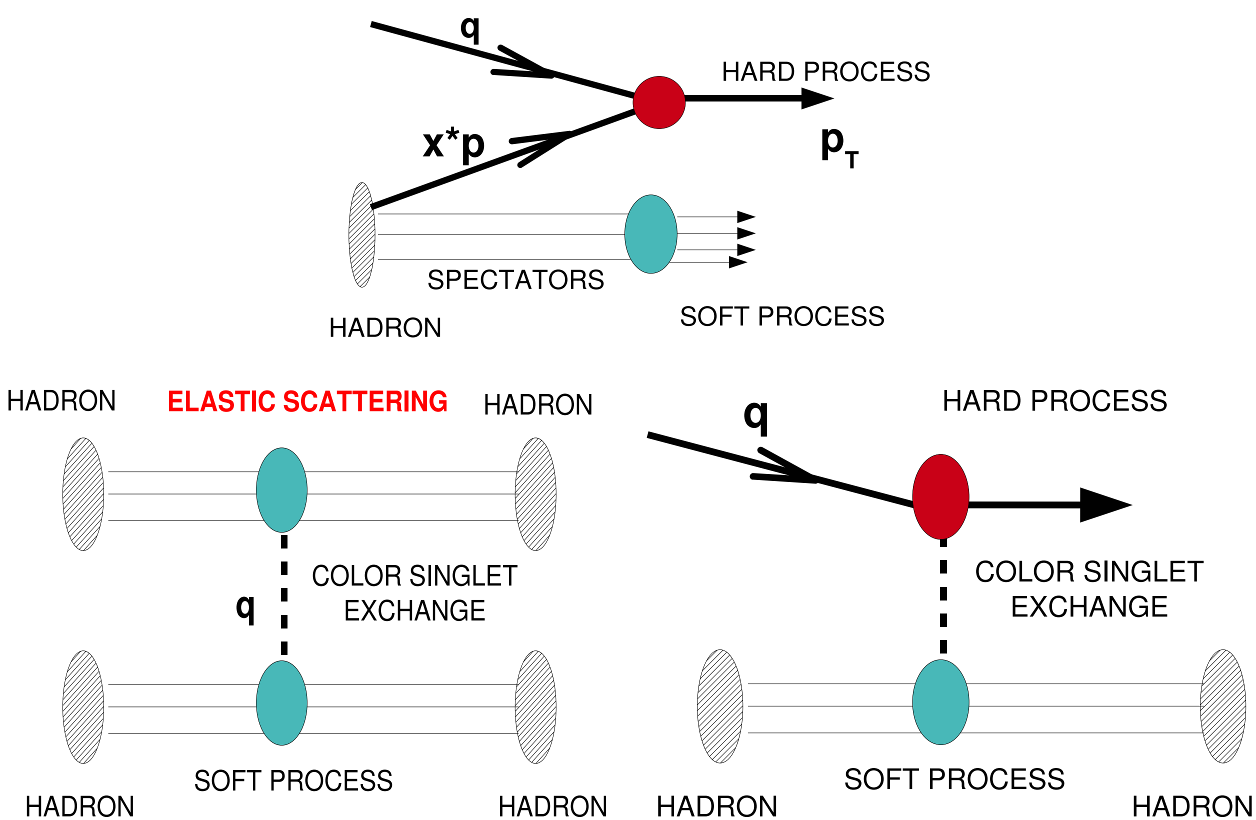
Introduction

QCD is the theory of the strong interactions - Hadronic process

$\Rightarrow$ **2 distinct classes**



The color singlet exchange $\longrightarrow$ Pomeron (Regge Theory - $s \gg |t|$)

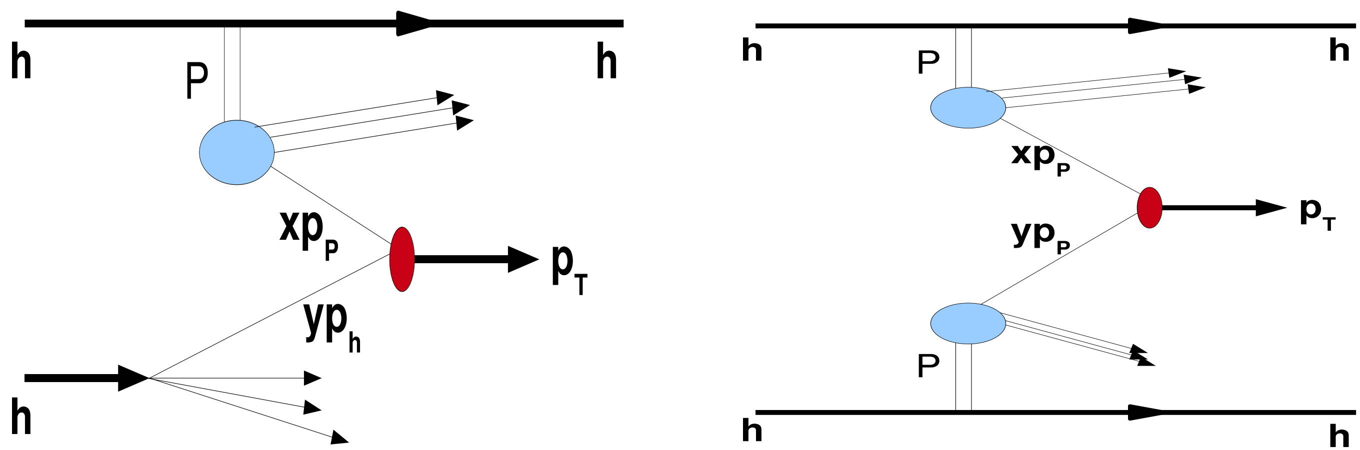
$$A_P(s,t) \sim s^{\alpha_0+\alpha t};\ \alpha_0 \sim .08\ \alpha \sim .25$$

Hard Diffraction

"hard diffraction provides a QCD laboratory where several aspects of QCD dynamics can be investigated."

Gunnar Ingelman

Soft and Hard process in the cross section



$$A_{SD} \sim f_{P/h} f_{q,g/P} f_{q,g/h} \sigma_{hard}$$

$$A_{DPE} \sim f_{P/h} f_{q,g/P} \sigma_{hard}$$

The pomeron nature remains elusive.

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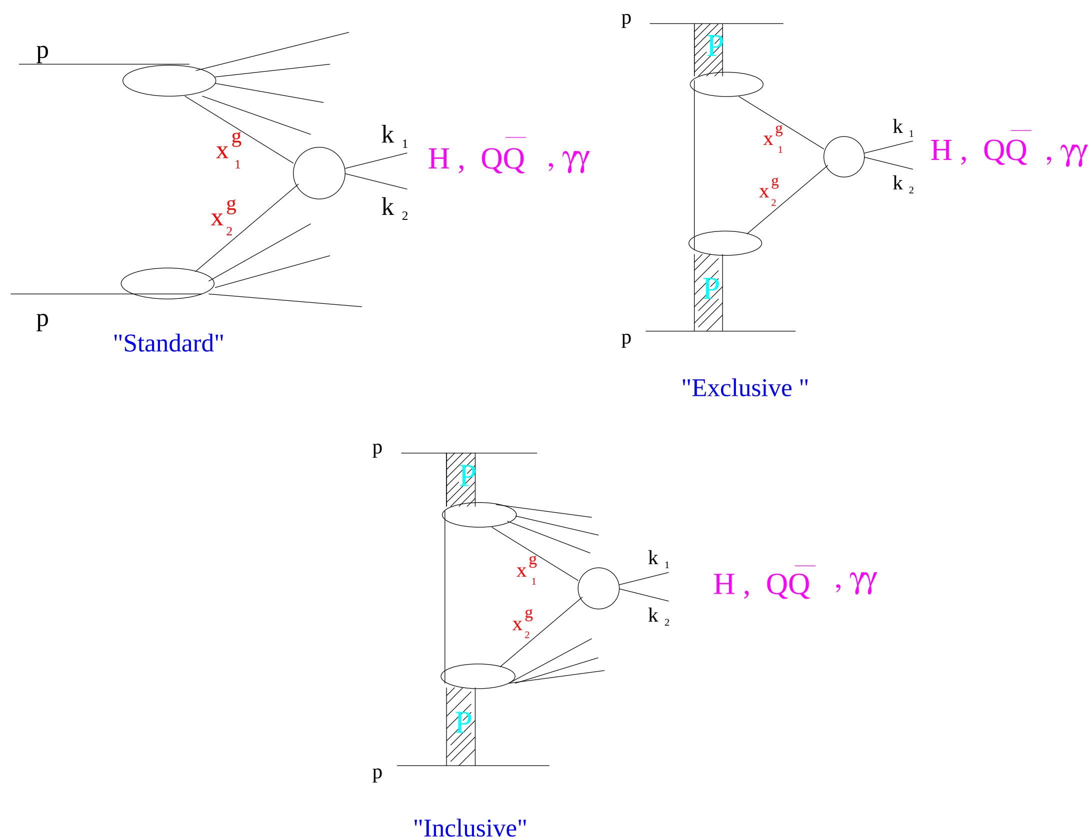
Double Pomeron Exchange

One can define two types of double pomeron exchange:

Exclusive: $hh \rightarrow h +$ heavy object $+ h$

Inclusive: $hh \rightarrow h + X +$ heavy object $+ Y + h$

h = proton at LHC and (anti)proton at Tevatron



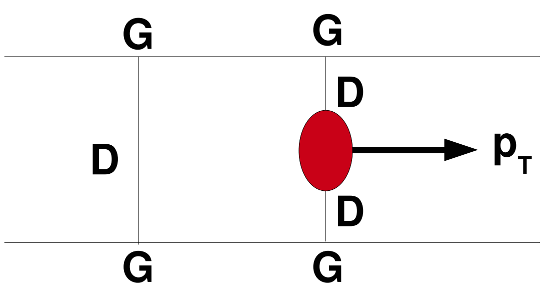
Exclusive DPE

Search for exclusive DPE is presently very active (Dijets and χ_c)
$\Rightarrow$ Higgs can be produced in such mode with good mass determination

Exclusive production of χ_{c_0} has been reported by the CDF collaboration, with an upper limit for the cross section of

$$\sigma_{exc}(p\bar{p} \to p + J/\psi + \gamma + \bar{p}) < 49 \pm 18(stat) \pm 39(sys)\ pb$$

Bialas-Landshoff Formalism for Exclusive Production (1991)



Calculate amplitude (|t|=0) with non-perturbative gluons (Landshoff-Nachtmann 1987) and reggeize them

We compare generator level results from the DPEMC Monte-Carlo, with the kinematics appropriate for small-mass, with CDF measurement. Inclusive DPE background addressed

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The Bialas-Landshoff Formalism

Extension of the BL formalism for diffractive Higgs production
Exclusive and inclusive diagrams are based on soft pomeron exchange

Inclusive DPE - normalization is fixed by data -BPR (2001)

$$d\sigma_{\chi}^{inc}(s) = C_{\chi}^{inc} \left(\frac{x_1^g x_2^g}{M_{\chi}^2} \right)^{2\epsilon} \delta\left(\xi_1 \xi_2 - \frac{M_{\chi}^2}{x_1^g x_2^g s} \right)$$
$$\prod_{i=1,2} \left\{ G_p(x_i^g, \mu)\; d^2 v_i dx_i^g \; \frac{d\xi_i}{1-\xi_i} \; \xi_i^{2\alpha' v_i^2} \exp(-2\lambda_{\chi} v_i^2) \right\}$$

$$d\sigma_{\chi}^{exc}(s) = C_{\chi} \left(\frac{s}{M_{\chi}^2} \right)^{2\epsilon} \delta\left[\frac{{M_{\chi}}^2}{s} - \frac{M_{diff}^2}{s} \right]$$
$$\prod_{i=1,2} \left\{ d^2 v_i \; \frac{d\xi_i}{1-\xi_i} \; \xi_i^{2\alpha' v_i^2} \; \exp(-2\lambda_{\chi} v_i^2) \right\}$$

Rapidity gap survival factor applied only for the exclusive case

C_{χ} depends contains a non pertubartive part due the quark-pomeron coupling $G^2/4\pi \sim 1$

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Full Kinematics for Exclusive DPE

The DPEMC Monte-Carlo is used to compare
the BL predicted cross sections with the CDF upper limit.

The generation method for high-mass ($M^2_{diff} >> |t|$) is based on the following steps:

$\longrightarrow$ Generate t_1, t_2 and $\xi_1 = 1 - \frac{k_z^{final}}{k_z^{initial}}$.

$\longrightarrow$ Exclusive events have the property that the full energy available in the center-of-mass is used to produce the diffractive object, or in other words there is no Pomeron remnant.

$\longrightarrow$ The value of ξ_2 is thus imposed by $M^2_{diff} \approx s\xi_1\xi_2$

This approximation is no longer true for low mass states (χ mesons)
$|t|$ is no longer $<< M^2_{diff}$
$\Rightarrow$ Need to derive full 4-momentum conservation

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Full Kinematics for Exclusive DPE

Using the approximation $m_p = m_{\bar{p}} = 0$ (mass of the colliding particles):

$$s = (k_p + k_{\bar{p}})^2 - (\vec{k_p} + \vec{k}_{\bar{p}})^2 + M_{diff}^2 + 2E_M(k_p + k_{\bar{p}}) - 2\vec{k_M} \cdot (\vec{k_p} + \vec{k}_{\bar{p}})$$

Defining

$$\Omega = -cos\theta_p cos\theta_{\bar{p}} + sin\theta_p sin\theta_{\bar{p}}(cos\varphi_p cos\varphi_{\bar{p}} + sin\varphi_p sin\varphi_{\bar{p}});$$

and applying conservation constraints, it can be shown that

$$M_{diff}^2 = s + 2k_p k_{\bar{p}}(1 - \Omega) - 2\sqrt{s}(k_p + k_{\bar{p}})$$

Using the definition of ξ:

$$\xi_{p,\bar{p}} = 1 - \frac{k_z^{final}}{k_z^{initial}} \Rightarrow k_{p,\bar{p}} = \frac{\sqrt{s}/2}{cos\theta_{p,\bar{p}}}(1 - \xi_{p,\bar{p}})$$

$$\frac{M_{diff}^2}{s} = 1 + \frac{(1-\xi_p)(1-\xi_{\bar{p}})}{2cos\theta_p cos_{\bar{p}}}(1 - \Omega) - \left(\frac{1-\xi_p}{cos\theta_p} + \frac{1-\xi_{\bar{p}}}{cos\theta_{\bar{p}}}\right)$$

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Full Kinematics for Exclusive DPE

Within the framework of DPEMC, we do the following:

- → Generate θ_1, θ_2 (following an exponential distribution), and ξ_1, which gives t_1
- → ξ_2 is then computed
- → The events are then weighted according to the cross section

$$\sin^2 \theta_{1,2} \sim \theta_{1,2}^2 = \frac{|t_{1,2}|}{(1-\xi_{1,2})(s/4)}$$

The new steps are thus to use the variables θ and ξ
$\Rightarrow$ avoid the cumbersome solution in terms of ξ and t.

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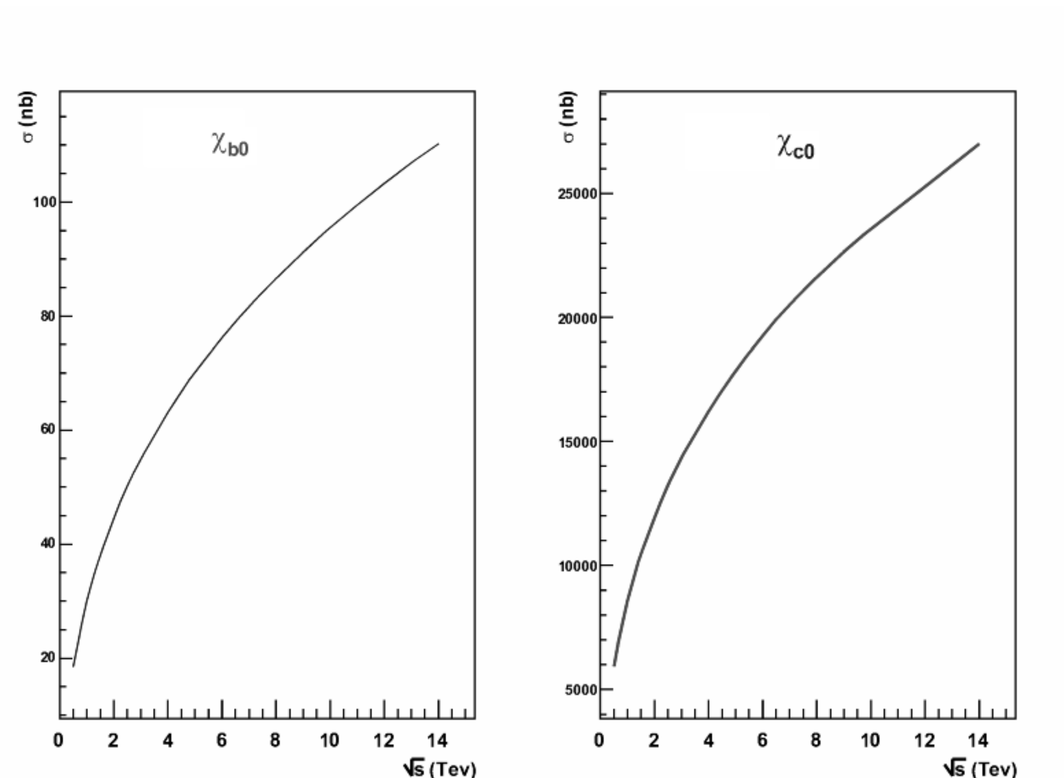
Exclusive and Inclusive χ Production

$\sigma(nb)$	Tevatron $\sqrt{s} = 1.96$ TeV	LHC $\sqrt{s} = 14$ TeV
$\sigma_{exc}(\chi_{c_0})$	1.17×10^3	0.804×10^3
$\sigma_{exc}(\chi_{b_0})$	4.4	3.29
$\sigma_{inc}(\chi_{c_0})$	1.8×10^4	4.8×10^4
$\sigma_{inc}(\chi_{b_0})$	20	1.8×10^2

Cross sections (in nb) for exclusive and inclusive production at the Tevatron and the LHC.



Exclusive Production cross section of χ_{b0} (left) and χ_{c0} mesons (right).

Comparison with CDF Limit

The CDF Collaboration has presented preliminary results for exclusive $J/\psi + \gamma$ production with the following cuts:

$$p_T(\mu^{\pm}) \geq 1.5 \text{ (GeV)}, \ |\eta(\gamma)| \leq 3.5 \text{ and } |\eta(\mu^{\pm})| \leq 0.6$$

and the upper limit provided is:

$$\sigma_{exc}(p\bar{p} \rightarrow p + J/\psi + \gamma + \bar{p}) < 49 \pm 18(stat) \pm 39(sys)\ pb$$

If we apply the CDF cuts at generator level

$$\sigma_{exc}(p\bar{p} \rightarrow p + \chi_{c0}(\rightarrow J/\psi\gamma) + \bar{p}) = 61 pb$$

To consider the non-exclusive background, which can enter directly in the experimental cross section, we considered the contamination due to quasi-exclusive events.

CDF removes the events with a mass fraction $F_M = \frac{M_\chi^2}{M_{diff}^2} > 0.85$. Since we do not have detector simulation, we apply many mass fraction cuts.

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Comparison with CDF Limit

Quasi-exclusive cross section (in pb) at the Tevatron after CDF cuts

gluon density in the Pomeron $\rightarrow (1-\beta)^{\nu}$**: HERA** $\nu = 0.0 \pm 0.6$**.**

Mass Fraction Cut	$\nu =$ 0	$\nu =$ -1	$\nu =$ -0.5	$\nu =$ 0.5	$\nu =$ 1
≥ 0.75	14.33	194.94	52.28	3.88	0.84
≥ 0.8	5.4	118.87	27.15	0.84	0.17
≥ 0.85	2.02	61.89	11.13	0.17	0
≥ 0.9	0.34	28.43	2.87	0	0
≥ 0.95	0.08	19.48	0.84	0	0

CDF cut	1	2	3	4	5
Exclusive cross section (pb)	5.56 $\times 10^3$	7.97 $\times 10^2$	5.25 $\times 10^2$	61.47	61.21

Exclusive cross section $\sigma_{exc}(p\bar{p} \rightarrow p + \chi_{c0}(\rightarrow J/\psi\gamma) + \bar{p})$ for each CDF cut:

1 - one muon with $p_T \geq 1.5$; 2 - one muon with $p_T \geq 1.5$ and $|\eta| \leq 0.6$;

3 - two muons with $p_T \geq 1.5$; 4 - two muons with $p_T \geq 1.5$ and $|\eta| \leq 0.6$;

5 - same constraint of the forth column plus one gamma with $\eta \leq 3.5$.

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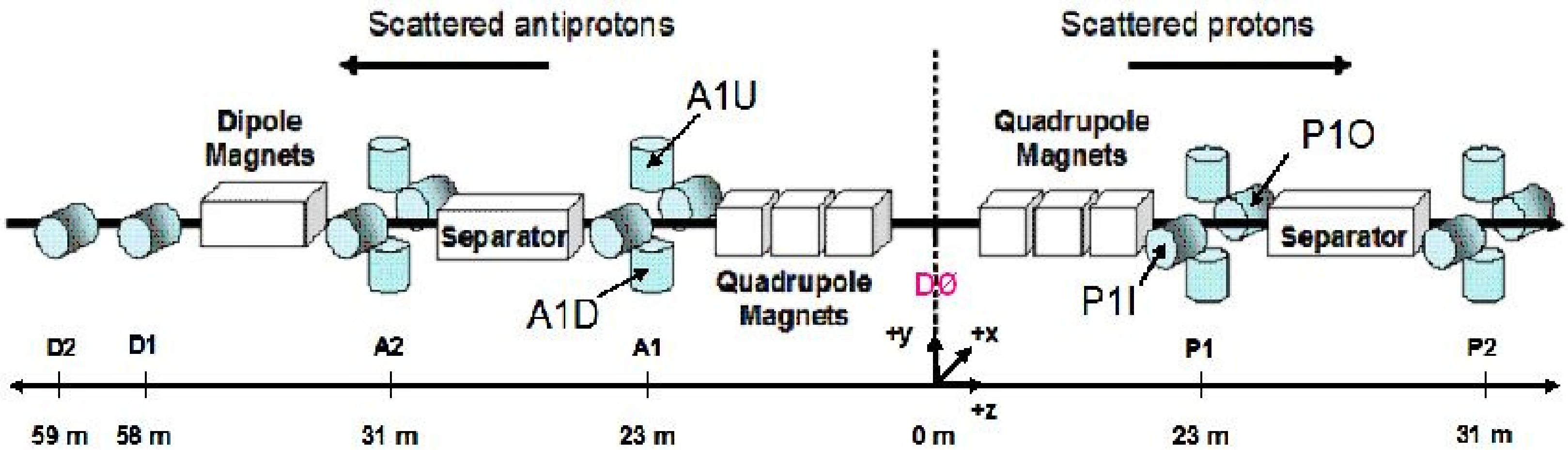
Possible Measurement at DØ

The roman pot detectors in the DØ collaboration can be used for (anti)proton tagging



Interfaced DPEMC generator with a code to propagate (anti)protons
Suggested cuts:

(($p_T(\mu^+) \geq 2.0$ (GeV) or $p_T(\mu^-) \geq 2.0$ (GeV))
$|\eta(\mu^\pm)| \leq 2.0$
$|\eta(\gamma)| \leq 3.0$)

Possible Measurement at DØ

Number of exclusive χ_{c_0} events (MC error $\sim 10\%$).

Regular Tevatron Stores - L = 100pb^{-1}				
Scenario	A	B	C	D
0	1.2 $\times 10^8$	2.6 $\times 10^6$	4.8 $\times 10^6$	2.9 $\times 10^5$
DØ selection	1.8 $\times 10^2$	2.7 $\times 10^1$	3.0 $\times 10^1$	1.5

Scenario 0 - all decay channels.
A - all (without p or $\bar{p}$ tagging);
B - tagged in the p side quadrupole;
C - tagged in the $\bar{p}$ side quadrupole
D - double tagged events in the quadrupoles.

One would need to use rapidity gap selection

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Exclusive χ_{C_0} Production at the LHC

The TOTEM/CMS acceptance for the high β^* optics and low ξ values is typically 90 %, for the range $0 < |t| < 1\ GeV^2$.

$\Rightarrow$ For 10 pb^{-1} of data, 5.3$\times 10^6$ double tagged events.

The lowest possible muon p_T cut at low luminosity is $p_T \geq 1.5$ (GeV) for $|\eta| \leq 2.4$.

Quasi-Exclusive cross section (in pb)

Mass Fraction Cut	$\nu =$ 0	$\nu =$ -1	$\nu =$ -0.5	$\nu =$ 0.5	$\nu =$ 1
≥ 0.9	1.35	138.11	17.88	0.34	0.17
≥ 0.95	0	13.83	1.18	0	0

Exclusive cross section (in pb)

Central cut	1	2	3	4
Total	3.74 $\times 10^3$	1.43 $\times 10^3$	3.64 $\times 10^2$	1.27 $\times 10^2$
After Totem Acceptance	3.03 $\times 10^3$	1.16 $\times 10^3$	2.95 $\times 10^2$	1.03 $\times 10^2$

1 - one muon with $p_T \geq 1.5$; 2 - one muon with $p_T \geq 1.5$ and $|\eta| \leq 2.4$;
3 - two muons with $p_T \geq 1.5$; 4 - two muons with $p_T \geq 1.5$ and $|\eta| \leq 2.4$.

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Conclusion

- Calculate diffractive production cross section for χ mesons using an extended version of the Bialas-Landshoff model , including the full kinematics needed for low mass states,
- The results for exclusive production at the Tevatron agree with a recent CDF upper limit for the exclusive production of χ_{c_0},
- The non-exclusive background (in particular “quasi-exclusive”) can reach similar levels as the exclusive signal,
  $\Rightarrow$ **CDF result is not conclusive about Exclusive Production**
- Exclusive χ_{c_0} production at the Tevatron, using the DØ forward proton detector is possible if a tight cut on the F$_M$ can be performed successfully.
- Exclusive production at the LHC, using the CMS/TOTEM detectors, depends again a high enough cut on the mass fraction

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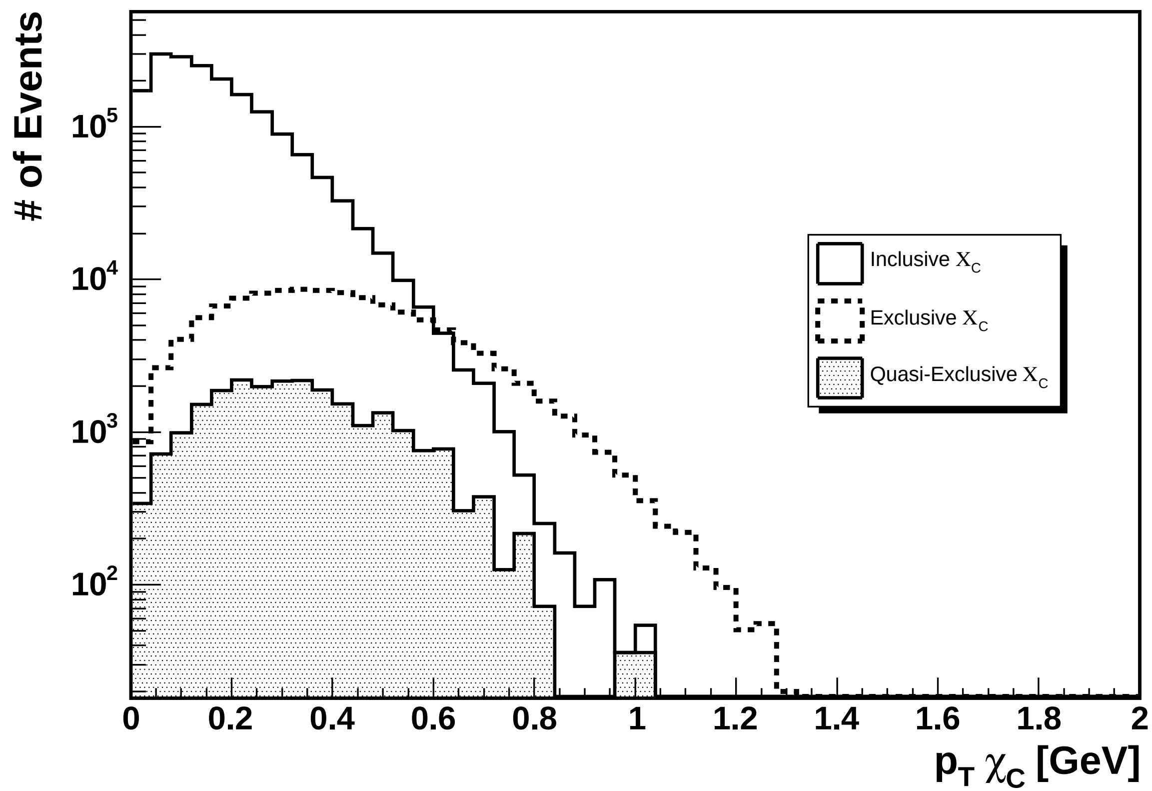
Comparison with CDF Limit



Exclusive model does not include Sudakov factors (**small for low masses**)